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NAVY ELECTRONICS LAB SAN DIEGO CALIF
LABORATORY EXPERIMENTS TO INVESTIGATE EFFECTS AND CAUSES OF DOP--ETC(U)
OCT 66 L STRAUSS, P H HAWKES

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NEW Technical Memorandum 1000

TECHNICAL MEMORANDUM TM-1000

LABORATORY EXPERIMENTS TO INVESTIGATE EFFECTS AND CAUSES OF DOPPLER SPREADING
IN HETERODYNE CORRELATORS.

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This memorandum describes a study undertaken to analyze in detail a signal-processing phenomena observed during sea tests and in the laboratory. It has been prepared to show others at NEL the extent of these effects in the particular signal-processing system used. Limited outside distribution is contemplated. This memorandum presents the results of a portion of continuing work on problem number E119.

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LABORATORY EXPERIMENTS TO INVESTIGATE EFFECTS AND CAUSES OF
DOPPLER SPREADING IN HETERODYNE CORRELATORS

1.0 PURPOSE OF STUDY

It has been reported in various publications and observed during recent sea trips that in a heterodyne correlator system such as employed by the LORAD equipment¹ correlation pulses (obtained as a result of target detection) can and do appear simultaneously on more than one comb-filter tooth.

During two local sea trips, analog tape data was taken of ten adjacent comb-filter teeth to observe these effects. When these tapes were reproduced in the Laboratory and recorded on Visicorder tape, spreading of these pulses across several filter teeth was observed.

This laboratory experiment has been undertaken to determine the extent of this spreading effect in the controlled environment of the Laboratory, thus getting away from possible sea medium effects.

Prior to the sea trip experiment, work on the laboratory signal processor² had indicated that frequency spreading can occur even under these "ideal" laboratory conditions. This situation was first noticed during the checkout and debugging phase following extensive modification of the laboratory equipment. The modifications allowed, for the first time, the selection of one of three system sample rates, and provided for the monitoring of individual comb-filter teeth.

¹NEL Report 1060, "LORAD Status Report", 9 October 1961, CONFIDENTIAL

²Described in NEL Technical Memorandum 846, "Laboratory Instrumentation for Sonar Signal Parameter Studies," by P. H. Hawkes.

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It was found that there was a 6 db correlation loss at the lower sample rate (200 Hz) compared with the two higher sample rates (400 Hz and 800 Hz) when processing a zero doppler 100 Hz bandwidth PN signal. An investigation showed that at the 200 Hz sample rate, the correlator output was divided nearly equally between two comb-filter teeth which were located a distance of two teeth on either side of the zero doppler tooth. This frequency splitting was not observed at the higher sample rates.

The cause of this problem was traced to slight frequency errors in the correlator's heterodyne oscillators. When the oscillators were replaced with precise frequency sources, the problem disappeared. It was experimentally determined that the optimum difference frequency was 99.85 Hz. This compares favorably with the theoretical value of 99.84 Hz which comes about from the following:

1. The Deltic has a basic clock rate of 1 MHz.
2. The Deltic is mechanized to correlate sixteen signals sequentially for 313 usec each.
3. The sampling period is thus:

$$313 \times 10^{-6} \times 16 = 5008 \text{ usec}$$

(a sampling frequency of approximately 200 Hz)

4. There is storage capacity for 939 bits of information, giving

$$939 \times 5008 \text{ usec} = 4.7 \text{ seconds of stored data}$$

5. The compression factor is:

$$\frac{\text{Time of information read in}}{\text{Time of information read out}} = \frac{939 \times 5008}{313} = 15,024$$

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6. The input bandwidth is related to the correlator output frequency as:

$$\frac{1.5 \times 10^6}{15,024} = 99.84 \text{ Hz}$$

where 1.5 MHz is the correlator output frequency for zero doppler.

The doppler spreading seen in the sea trip data closely resembled the effects observed during the above described laboratory experiment. Therefore, experiments were undertaken for the purpose of establishing a quantitative measure of the effect of heterodyne difference frequency on correlator output.

This study is comprised of two parts:

- (1) Determination of the heterodyne oscillator frequency accuracy requirements (such that a zero doppler target appears on the center tooth of the comb-filter), and
- (2) Determination of correlation pulse spreading across the teeth when an artificially-dopplerized target is used.

2.0 PARAMETERS

These experiments have been conducted with the Laboratory Processor using the following system parameters:

Signal Type: Pseudorandom noise

Center Frequency: 1500 Hz

Bandwidth: 100 Hz

Sample Rates: 200, 400, and 800 Hz

Reference Heterodyne Frequency: 1450.00

Signal Heterodyne Frequencies: 1549.00 to 1550.60 Hz

Pseudorandom Noise Generator Frequencies (generating artificial doppler):

3998.50 to 4004.00 Hz (for outputs on from teeth 12 through 23)

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3.0 EQUIPMENT

A block diagram of the system is shown in Figure 1. It consists of the Laboratory Processor and Deltic (the latter modified by a Multiplex Buffer providing ability to operate the system at various sample rates); a Frequency Synthesizer, General Radio, type 1161-A; and a Honeywell 1508 Visicorder (12-channel).

4.0 PROCEDURES

4.1 Heterodyne Difference Frequency Accuracy Tests

4.1.1 The equipment was turned on and allowed to stabilize.

4.1.2 A sample rate was chosen.

4.1.3 Comb-filter teeth 12 through 23 were connected to Visicorder channels 1 through 12, respectively.

4.1.4 A reference signal heterodyned at 1450.00 Hz by the Frequency Synthesizer (F.S.) was stored in the Deltic.

4.1.5 The F.S. was then set to about 1549.84 Hz to observe that the system was operating correctly and that correlation spikes were being developed at comb-filter tooth 17.

4.1.6 The F.S. frequency was then varied from 1549.00 Hz to 1550.60 Hz in chosen steps. At each step seven or eight correlation spikes were allowed to be recorded on the Visicorder tape. Points were obtained closer together in the region of 1549.80 to 1549.90 Hz to observe the detail near the middle of the zero doppler area.

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4.1.7 The above steps were repeated for the other sample rates of 400 and 800 Hz.

4.2 Artificially-Dopplerized Tests

4.2.1 Steps 4.1.1 through 4.1.3 were performed.

4.2.2 For a signal heterodyne oscillator, the regular 1550.00 Hz crystal oscillator card (with a measured frequency of 1550.28 Hz) was used in the Deltic. The 4000.00 Hz tuning-fork oscillator was used to drive the pseudorandom generator.

4.2.3 The Frequency Synthesizer was set to 1450.45 Hz and used as the reference heterodyne oscillator.

4.2.4 After the above reference was stored in the Deltic, the PN Generator oscillator card was removed and the F.S. disconnected as the reference heterodyne oscillator. The F.S. was then reset to 4001.52 Hz³ and applied as the PN generator oscillator. Thus the PNG frequency could be varied, acting (in this system) as an artificially-dopplerized target.

4.2.5 The F.S. signal was then varied from 3998.50 to 4004.00 Hz in steps and data taken as in 4.1.6 and 4.1.7.

5.0 DATA ANALYSIS

For each sample rate the Visicorder tapes were analyzed by measuring the recorded correlation pulse amplitudes and averaging these amplitudes for each frequency and for each affected tooth. These averaged amplitudes were then

³The actual (measured) frequency developed by the PN generator oscillator card was 4001.52 Hz. This was the zero doppler frequency used.

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recorded on matrix charts, Figures 2 and 9. Curves were drawn from this data for each tooth over the frequency range showing relative improvements of the correlation pulse amplitude at the different sample rates.

6.0 RESULTS

6.1 Matrix Chart and Doppler Tooth Curves

6.1.1 From Figures 3 through 7⁴ it is seen that varying the signal heterodyne frequency with respect to the reference heterodyne frequency gives a simulated doppler effect. As the difference becomes greater than 99.90 Hz (zero doppler) signals appear on the higher-numbered doppler teeth giving the effect of an opening target. Frequency differences less than 99.90 Hz give the opposite effect.

The comb-filter teeth are seen to peak at about 0.2 Hz (input equivalent doppler) from each other; this being the doppler resolution of the system. It is given by $\frac{1}{T}$ where T is the length of the transmitted pulse (see paragraph 6.3).

6.1.2 Amplitude

Figures 3 through 7 also show the effect of sample rate on correlation pulse amplitude. These amplitudes are compared in Figure 8 and show that considerable improvement in amplitude is obtained at the higher sample rates. This improvement is substantial in going from 200 to 800 Hz (off-zero doppler) because of a "spreading" phenomena which tends to put the pulse energy into more than one tooth, diluting the signal seen on the correct tooth.

⁴These figures are of simultaneous results but have been put on separate sheets for clarity.

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It was observed that a correlation will always appear on more than one tooth. Depending on the incoming doppler frequency, the signal will either match exactly the center frequency of a particular tooth or be off slightly one way or the other. In the former case, almost all of the signal is seen at the tooth's output with a little seen on adjacent teeth. In the latter case, the signal energy is split among adjacent teeth depending on the incoming frequency and the accuracy of the comb-filter teeth frequencies.

6.2 Heterodyne Difference Frequency Accuracy

It is seen from Figure 5 that the correlation signal on tooth 17 (designated as zero doppler) peaks at 1549.84 Hz for the 200Hz sample rate and about 1549.90 Hz for the 400 and 800 Hz sample rates. Thus, the difference frequency for the signal and reference heterodyne oscillators is 1549.84 - 1450 or 99.84 Hz for the 200 Hz sample rate, which is identical to the calculated value (page 4). At the higher sample rates the difference frequency is somewhat higher (99.90 Hz).

6.3 Heterodyne Frequency Stability

It is desired that a zero doppler target appear only on tooth 17. Stability requirements on the heterodyne oscillators are obtained from the following:

The doppler resolution is $\frac{1}{T} = \frac{1}{4.7 \text{ sec}} = 0.213 \text{ cycles at the input to the system.}$

It is related to the system output via the compression factor, 15,024, giving an output resolution of $0.213 \times 15,024 = 3,200 \text{ Hz.}$ Thus, adjacent comb-filter teeth are 3,200 Hz apart. This is the bandwidth of each comb-filter tooth.

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The stability of the heterodyne oscillators must be such that under worst case conditions (signal and reference frequencies diverging) the difference frequency be accurate to one-half tooth resolution, or $\frac{0.213}{2} = 0.107$ Hz.

Using 99.90 Hz as the correct heterodyne frequency difference, the signal oscillator would be 1549.90 Hz and the reference oscillator, 1450 Hz. A worst-case condition would put the signal oscillator at $1549.90 + \frac{0.107}{2} = 1549.9535$ Hz and the reference oscillator at $1450 - 0.053 = 1449.9465$ Hz. This gives stability requirements of 0.00345% for the signal and 0.00368% for the reference oscillators.

6.4 Artificially-Dopplerized Signals

Figures 10 through 14 show the effects of varying the PN generator oscillator to simulate dopplerized targets. As the frequency is increased, a closing target is simulated and signals emerge from the lower teeth (with respect to tooth 17). The opposite is true for frequencies less than that required for zero doppler.

6.4.2 Doppler Resolution

Doppler resolution can be obtained in terms of the PN Generator clock frequency as follows:

$$\frac{0.213}{1500} = \frac{f}{4000}$$

$$f = \frac{0.213 \times 4000}{1500} = 0.568 \text{ Hz}$$

It can be seen from the curves that the peaks of adjacent teeth are approximately 0.6 Hz apart. It was also observed that the 200 Hz sample rate caused

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a "spreading" effect at off-zero doppler frequencies similar to that described in paragraph 6.1.2. This spreading was seen to become worse as the frequency was raised or lowered from the center frequency of 4001.52 Hz. It was observed that an input signal giving an output at tooth 1 also gave an output on tooth 34 and visa versa.

7.0 CONCLUSIONS

7.1 Heterodyne-Frequency Oscillator Accuracy and Stability

The above discussed data has shown the need for a very accurate difference frequency as derived from the signal and reference heterodyne oscillators. This must be 99.90 Hz for the correlation pulse to appear on tooth 17 for a zero doppler target at sample rates of 400 and 800 Hz. Due to the "spreading effect" seen at the 200 Hz sampling rate, too much amplitude is lost as compared with the higher sample rates. Therefore, this sampling rate should not be used in a heterodyne correlator of this type.

The stability requirements on these oscillators show that in order to have a correlation pulse appear where it should with a particular doppler target, a frequency stability of $\pm 0.003\%$ is required in the worst case.

7.2 Artificially-Dopplerized Targets

With correct heterodyne oscillator frequencies stored in the Deltic, it has been shown that a "spreading effect" is very evident at the 200 Hz sample rate; to the extent that a signal dopplerized to appear at tooth 1 will also appear at tooth 34.

At the 400 and 800 Hz sample rates, correlation pulses will appear on two or three adjacent teeth but will not be spread across large portions of the comb-filter bank.

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Recently, the heterodyne oscillators were removed from the Deltic used on the BAYA and measured very accurately. It was seen that they differed by 100.45 Hz instead of the desired 99.84 Hz (at 200 Hz). Thus there was good reason for some of the doppler spreading observed in the sea data. Sea medium effects could account for a portion of this phenomena and will be explored in the future.

Spreading effects at 200 Hz similar to those observed during sea tests have been duplicated in the Laboratory. They can be minimized by having accurate and stable heterodyne oscillators and by using sample rates in excess of 200 Hz.

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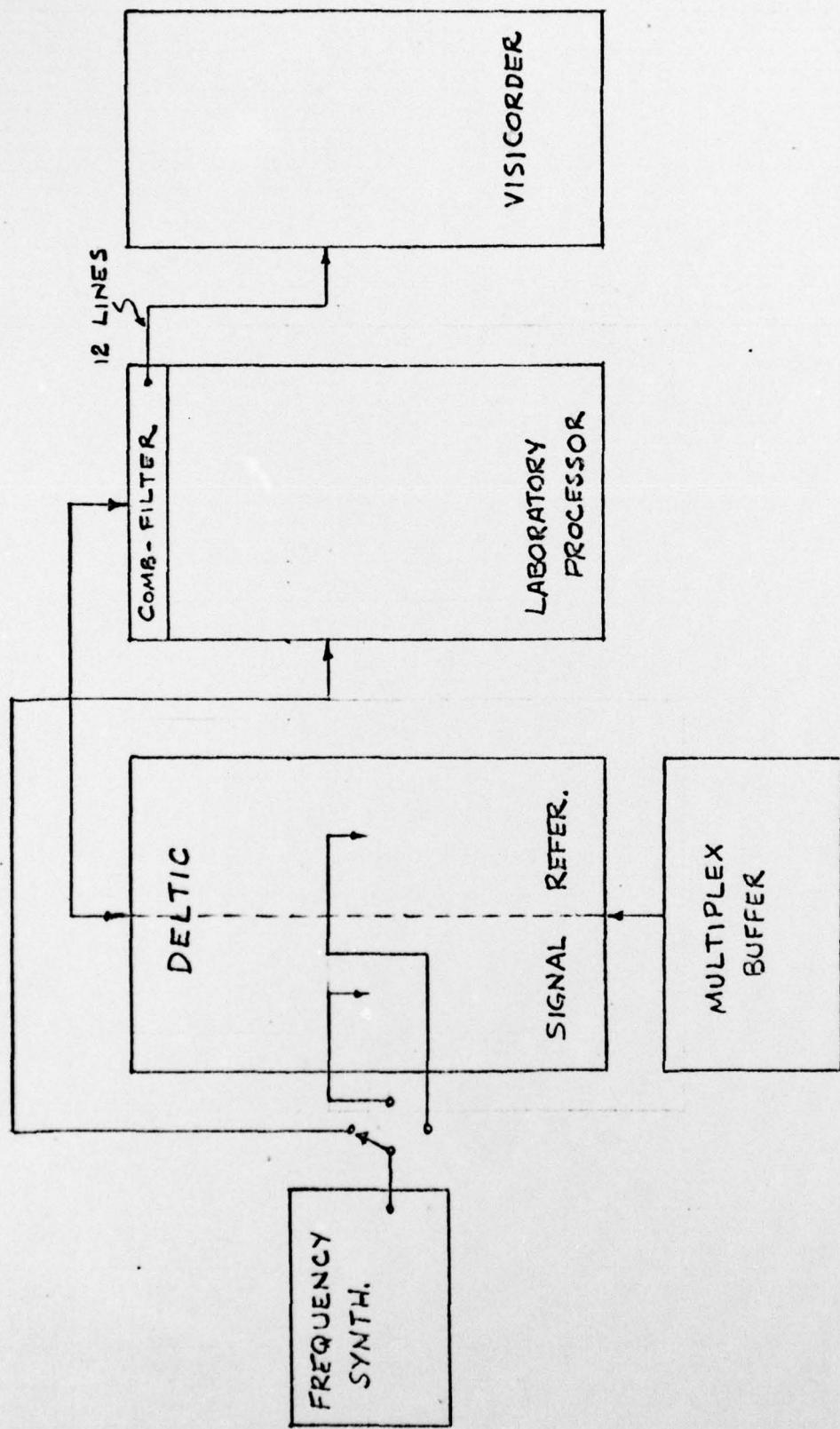


Fig. 1. EXPERIMENT SET-UP

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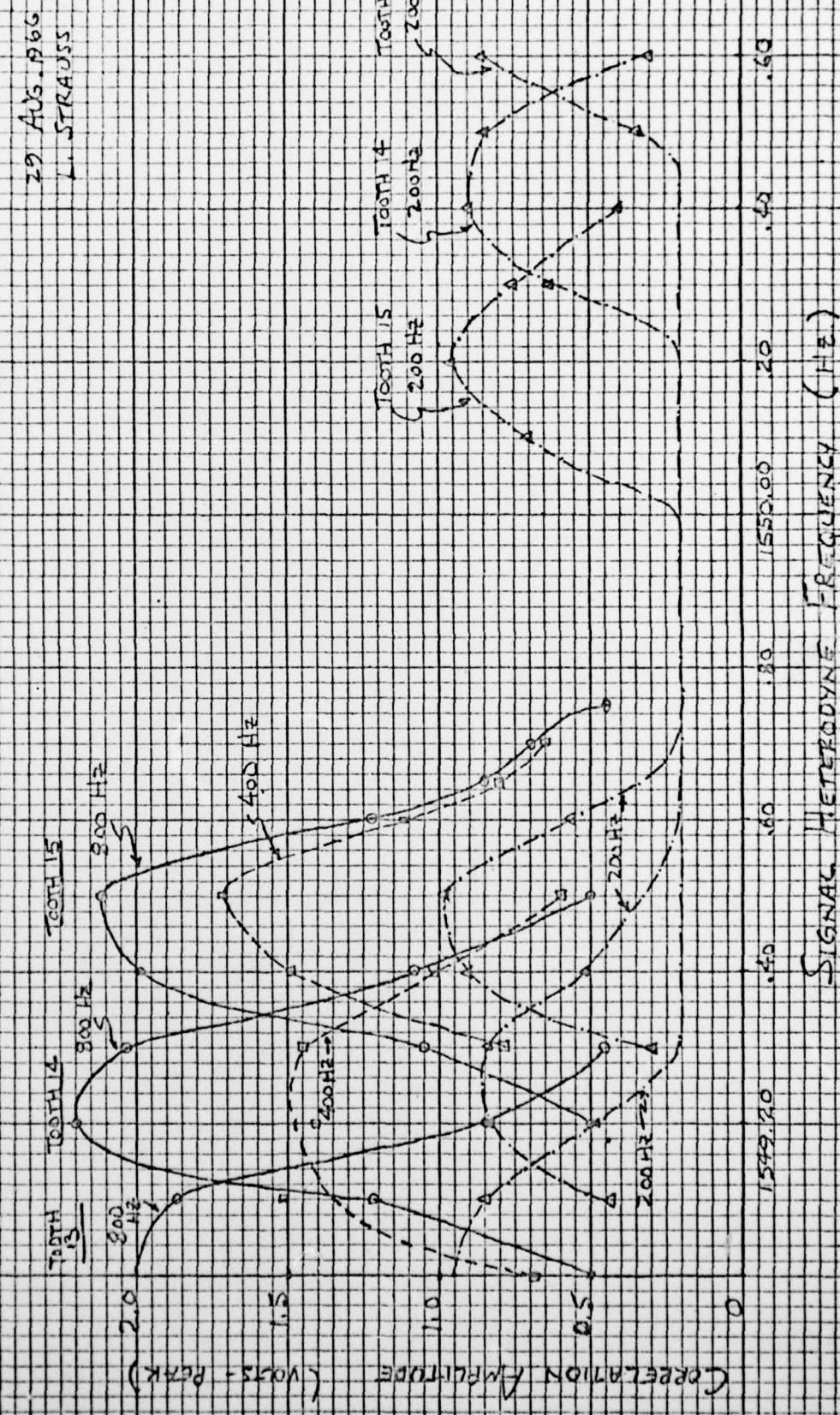
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Figure 2. Heterodyne-Frequency Accuracy Matrix

KOE 10 X 10 TO THE INCH 46 0702
 KUEPPEL & SISK CO.
 MADE IN U.S.A.

CORRELATION AMPLITUDE VS. SIGNAL HETERODYNE FREQUENCY

for SAMPLING RATES OF 200, 400, & 800 Hz.

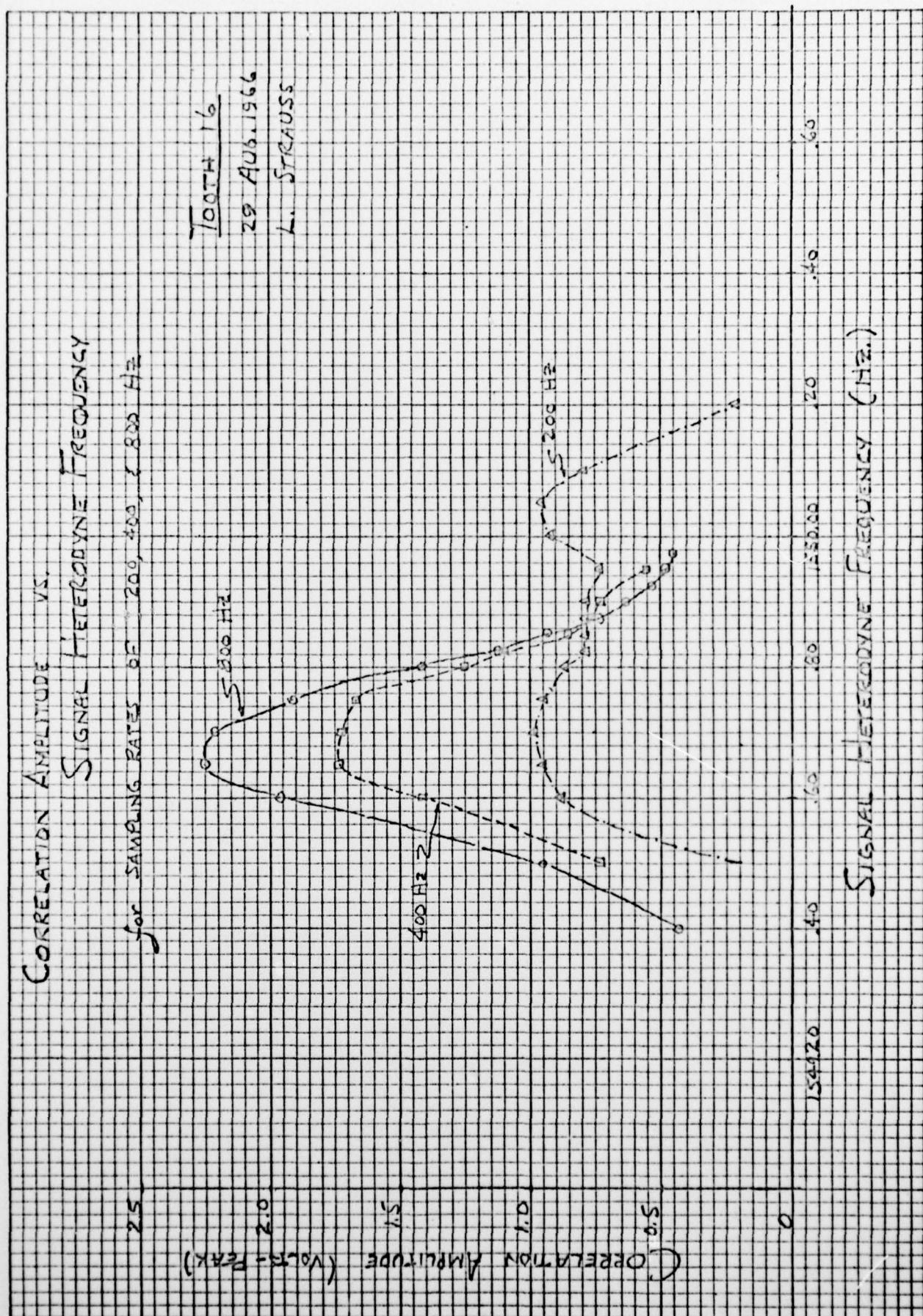


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Figure 3. Correlation Amplitude vs. Signal Heterodyne Frequency for Sampling Rates of 200, 400 and 800 Hz for teeth 13, 14 & 15

K 10 X 10 TO THE INCH 43-0702
7 X 10 INCHES
MADE IN U.S.A.
KRUPP & ECKER CO.

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Figure 4. Correlation Amplitude vs. Signal Heterodyne Frequency for Sampling Rates of 200, 400 and 800 Hz for tooth 16

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7 X 10 INCHES MADE IN U.S.A.
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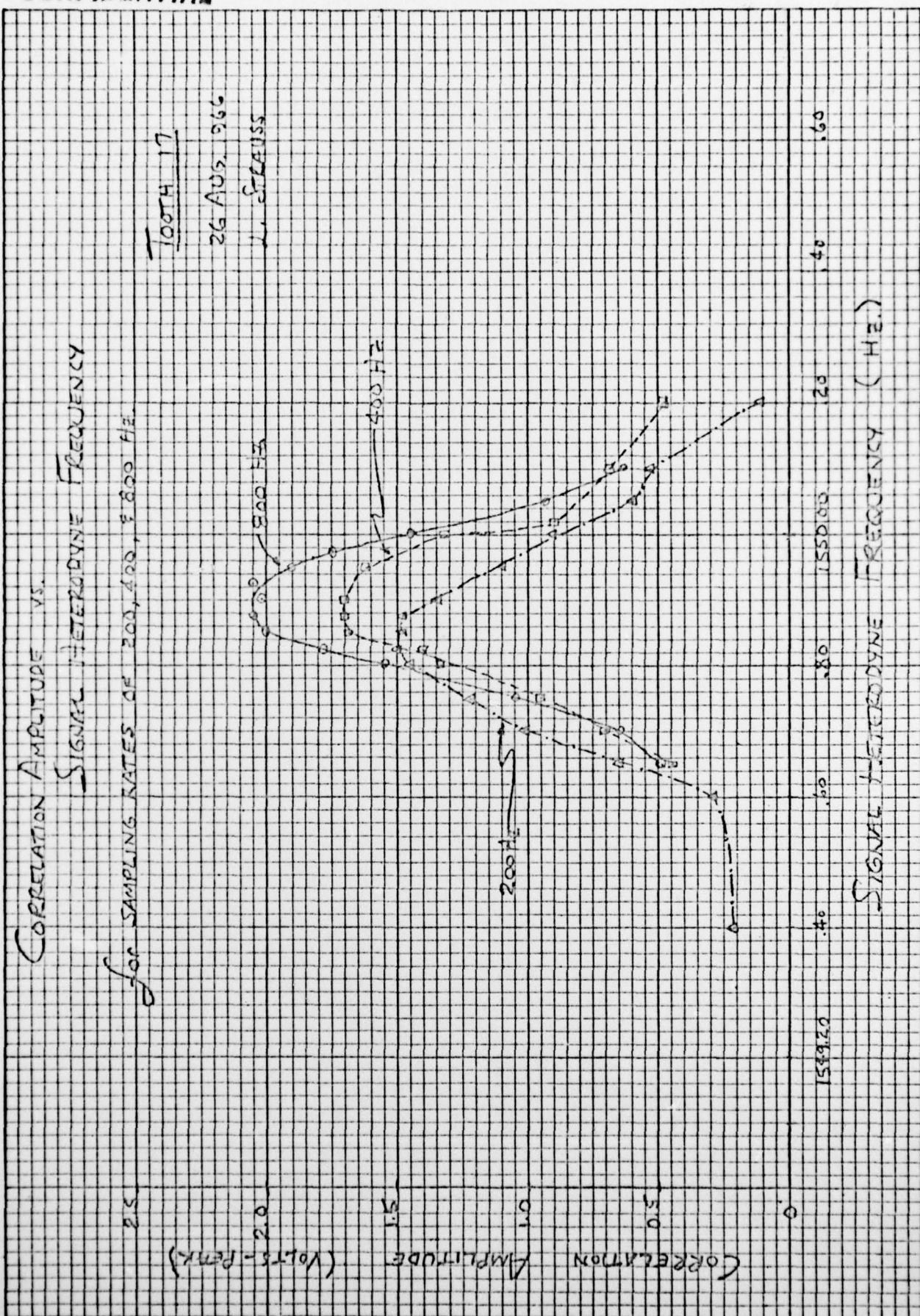
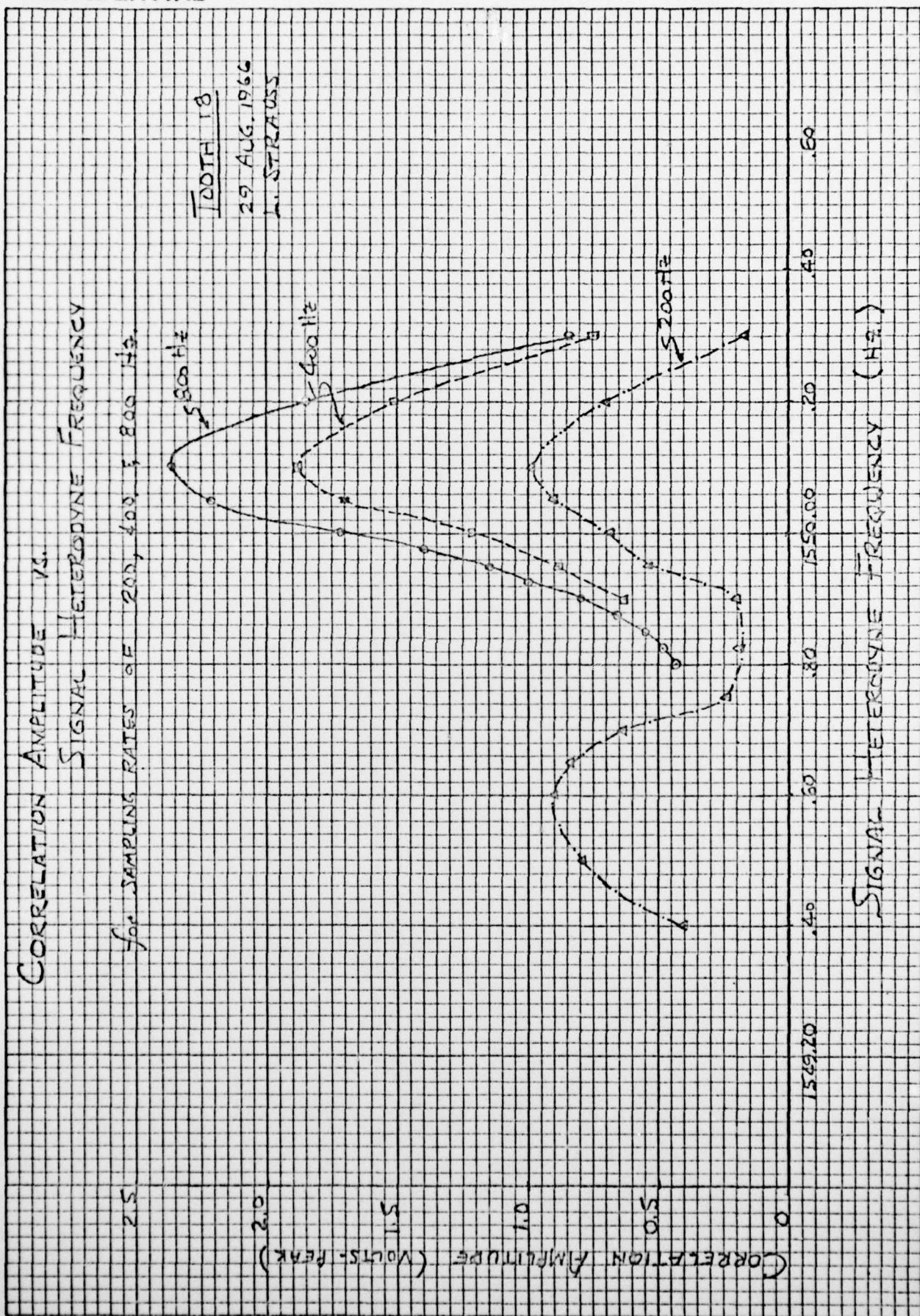


Figure 5. Correlation Amplitude vs. Signal Heterodyne Frequency for Sampling Rates of 200, 400 and 800 Hz for tooth 17

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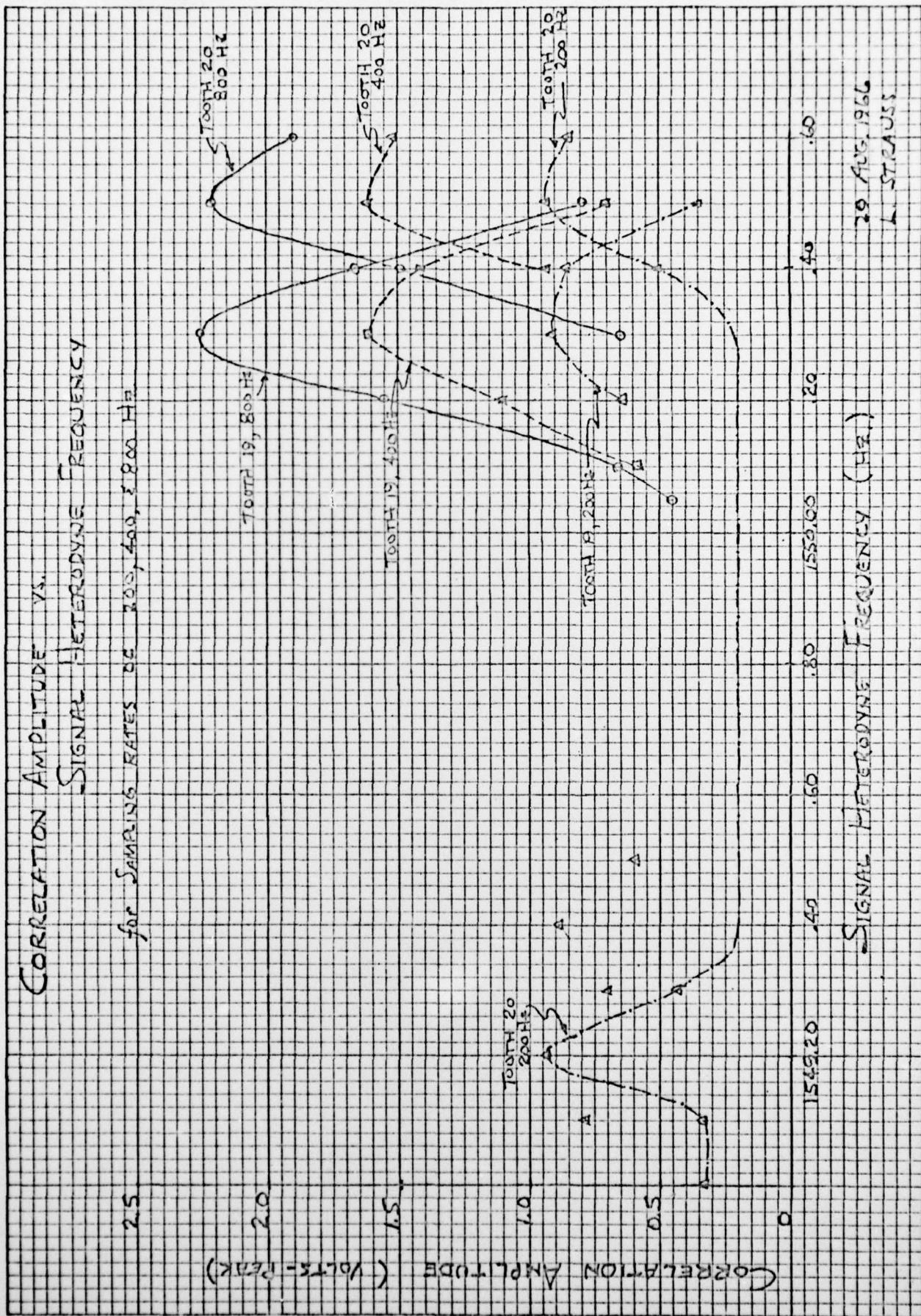


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Figure 6. Correlation Amplitude vs. Signal Heterodyne Frequency for Sampling Rates of 200, 400 & 800 Hz for tooth 18.

KOE 10 x 10 TO THE INCH 460702
7 x 10 INCHES MADE IN U.S.A.
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Figure 7. Correlation Amplitude vs. Signal Heterodyne Frequency for Sampling Rates of 200, 400 & 800 Hz for Teeth 19 & 20

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Tooth Sample Rate	db Down From 800 Hz Sample Rate	
	200 Hz	400 Hz
14	8.3	3.4
15	6.5	1.8
16	7.0	2.1
17	2.8	1.8
18	7.4	1.8
19	8.0	3.0
20	7.3	2.7

Figure 8. Correlation Amplitude for Different Sample Rates

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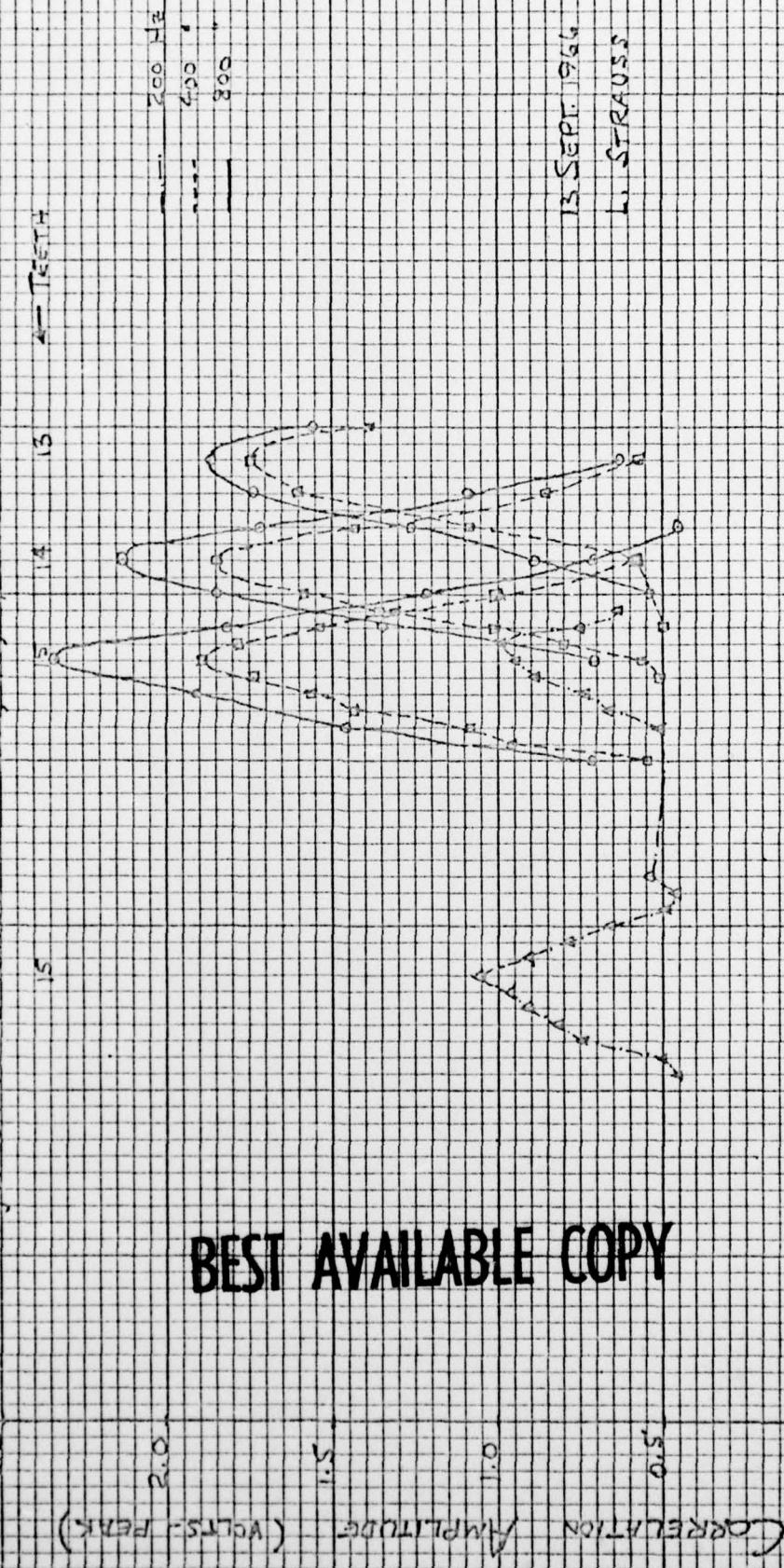
Teeth	Sample Rate Per Unit Proc. (Hz)	200	400	800	1600	3200	6400	12800	25600	51200	102400	204800	409600	819200	1638400	3276800	6553600	13107200	26214400	52428800	104857600	209715200	419430400	838860800	1677721600	3355443200	6710886400	13421772800	26843545600	53687091200	107374182400	214748364800	429496729600	858993459200	1717986918400	3435973836800	6871947673600	13743895347200	27487790694400	54975581388800	109951162776000	219902325552000	439804651104000	879609302208000	1759218604160000	3518437208320000	7036874416640000	14073748832000000	28147497664000000	56294995328000000	112589990656000000	225179981312000000	450359962624000000	900719925248000000	1801439850496000000	3602879700992000000	7205759401984000000	14411518803968000000	28823037607936000000	57646075215872000000	115292150437440000000	230584300874880000000	461168601749760000000	922337203499520000000	1844674406998400000000	3689348813996800000000	7378697627993600000000	1475739525596800000000	2951479051193600000000	5902958102387200000000	1180591620476400000000	2361183240952800000000	4722366481905600000000	9444732963811200000000	18889465927622400000000	37778931855244800000000	75557863710489600000000	15111572742097600000000	30223145484195200000000	60446290968390400000000	12089258193678080000000	24178516387356160000000	48357032774712320000000	96714065549424640000000	193428131098849280000000	386856262197698560000000	773712524395397120000000	1547425048790794240000000	3094850097581588480000000	6189700195163176960000000	12379400390326353920000000	24758800780652707840000000	49517601561305415680000000	99035203122610831360000000	198070406245221662720000000	396140812490443325440000000	792281624980886650880000000	1584563249761773301760000000	3169126495523546603520000000	6338252990547093207040000000	12676505981094186414080000000	25353011962188372828160000000	50706023924376745656320000000	101412047848753491328640000000	202824095697506982657280000000	405648191395013965314560000000	811296382789981930629120000000	1622592765779963861258240000000	3245185531559927722516480000000	6490371063119855445032960000000	1298074212623971089065920000000	2596148425247942178131840000000	5192296850495884356263680000000	10384593700991768712527360000000	20769187401983537425054720000000	41538374803967074850109440000000	83076749607934149700218880000000	166153498018868295400437760000000	332306996037736590800875520000000	664613992075473181601751040000000	1329227980150946363203502080000000	2658455960301892726407004160000000	5316911920603785452814008320000000	10633823841207770905628016640000000	21267647682415541811256033280000000	42535295364831083622512066560000000	85070590729662167245024013120000000	17014118145932434489048026240000000	34028236291864868978096052480000000	68056472583729737956192010960000000	13611294516745947912384021920000000	27222589033491895824768043840000000	54445178066983791649536087680000000	10889035613396758329907217360000000	21778071226793516659814434720000000	43556142453587033219628869440000000	87112284907174066439257738880000000	17422456981434813287851547760000000	34844913962869626575703095520000000	69689827925739253151406185040000000	13937965585147850630281236080000000	27875931170295701260562472160000000	55751862340591402521124944320000000	11150372468118280504224888640000000	22300744936236561008449777280000000	44601489872473122016895554560000000	89202979744946244033791109120000000	178405959489892888067582218240000000	356811918979785776135164436480000000	713623837959571552270328872960000000	142724767919534310454065775920000000	285449535839068620908131551840000000	570898571678137241816263103680000000	114179714335627482363252620736000000	228359428671254964726505241472000000	456718857342509929453010482944000000	913437714685019858906020965888000000	1826875429370039717812041937760000000	3653750858740079435624083875520000000	7307501717480158871248167750400000000	14615003434960357742483235502400000000	29230006869920715484966471004800000000	58460013739841430969932942009600000000	116920027479682658398658884019200000000	233840054959365316797317768038400000000	467680109918730633594635536076800000000	935360219837461267189271072153600000000	1870720439674922534378540144307200000000	3741440879349845068757080288614400000000	7482881758699690137514160577228800000000	14965763517399380275028321154457600000000	29931527034798760550056642308915200000000	59863054069597521100113284617828800000000	11972610813919504220226568923576000000000	23945221627839008440453137847152000000000	47890443255678016880906275694304000000000	95780886511356033761812551388608000000000	19156177274678066752362502777216000000000	38312354549356133504725005554432000000000	76624709098712266709450011108864000000000	15324941819742453341880022217728000000000	30649883639484906683760044435456000000000	61299767278969813367520088870912000000000	12259953455793962673504017741824000000000	24519906911587925347008035483648000000000	49039813823175850694016070967296000000000	98079627646351701388032141934592000000000	196159255292703402776064283869184000000000	392318510585406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4000000	318164672800000000000000379552999800000000398222224000000	636329345600000000000000189864999800000000197944444400000

KODAK 10 X 10 TO THE INCH 46 0702
7 X 10 INCHES MADE IN U.S.A.
KREUPPEL & ESSER CO.

CONFIDENTIAL

ARTIFICIALLY-DOPPLERIZED SIGNALS

FOR SAMPLING RATES OF 200, 400, & 800 Hz



CONFIDENTIAL

PIN GENERATOR OSCILLATOR FREQUENCY (Hz)

3994.00 4000.00 4002.00 4003.00 4004.00

13 SEPT. 1964

L. STRAUSS

Figure 10. Artificially-Dopplerized Signals for Sampling Rates of 200, 400 and 800 Hz for Teeth 13, 14 & 15

Ko 10x10 TO THE INCH 46 0702
7x10 INCHES. HANOVER,
REUPPEL & ESSER CO.

ARTIFICIALLY - DOPPLERIZED SIGNALS

For SAMPLING RATES OF 200, 400, & 800 Hz

ToOTH 16

9 Sept. 1966

L. STRAUSS



BEST AVAILABLE COPY

CONFIDENTIAL

PN GENERATOR CLOCK FREQUENCY (Hz)

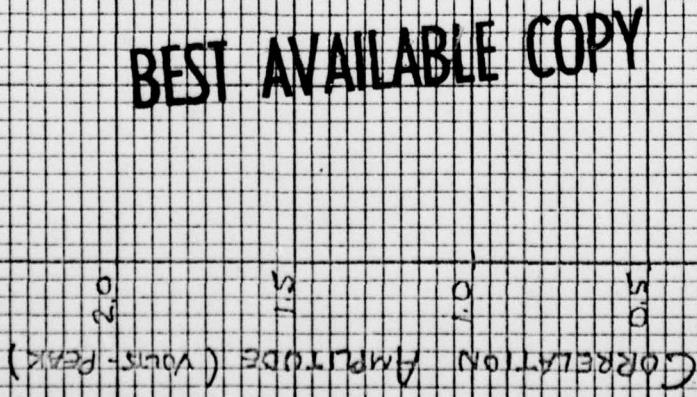
Figure 11. Artificially-Dopplerized Signals for Sampling Rates of 200, 400 and 800 Hz for Tooth 16

K-E 10 X 10 TO THE INCH 46-0702
7 X 10 INCHES MADE IN U.S.A.
KEUFFEL & ESSER CO.

CONFIDENTIAL

ARTIFICIALLY-DOPPLERIZED SIGNALS

For SAMPLING RATES OF 200, 400, & 800 Hz.



Tooth 17
9 Sept. 1956
L. STRAUSS

PW GENERATOR OSCILLATOR FREQUENCY (Hz)
399.00 400.00 400.00 400.00 400.00 400.00

CONFIDENTIAL

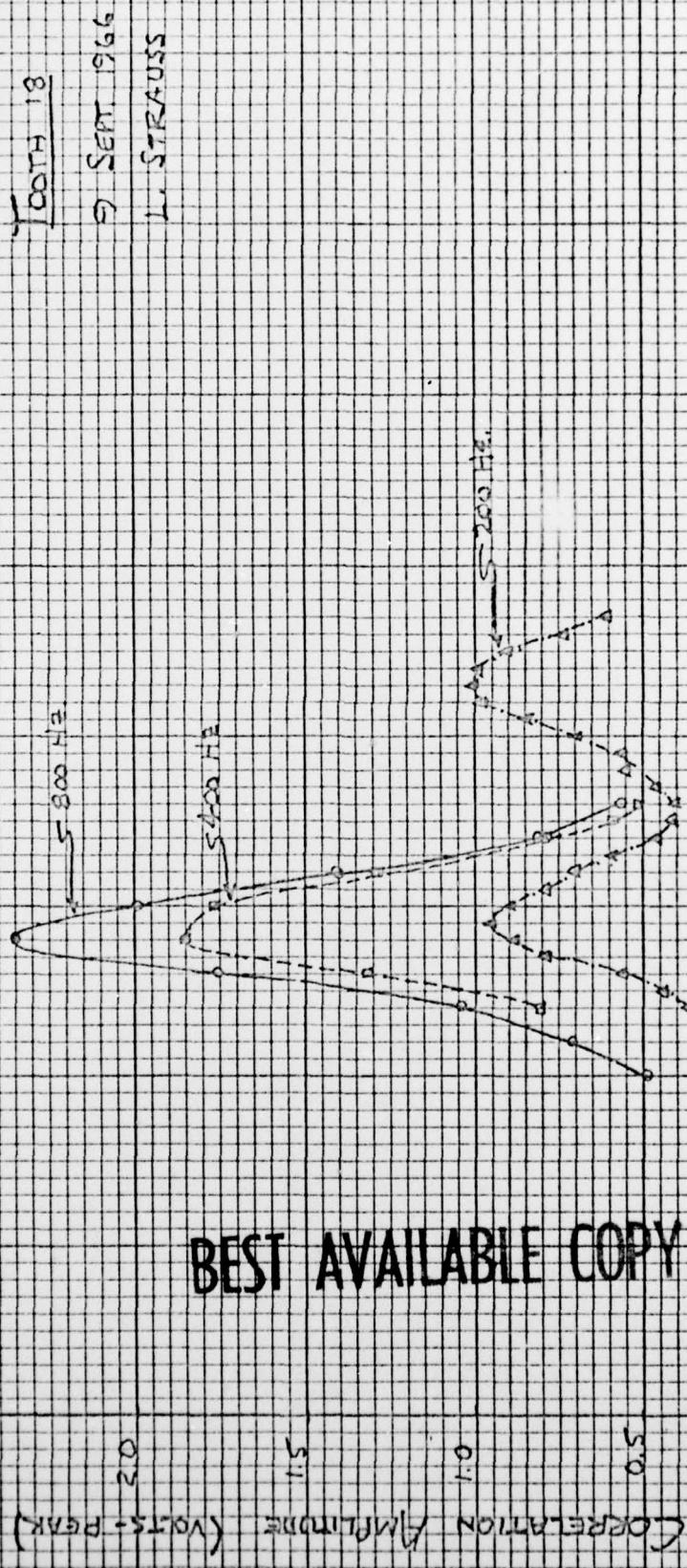
Figure 12. Artificially-Dopplerized Signals for Sampling Rates of 200, 400 and 800 Hz for Tooth 17

KoE 10 X 10 TO THE INCH 46 0702
7 x 10 INCHES MADE IN U.S.A.
KRUPP & ESSER CO.

CONFIDENTIAL

ARTIFICIALLY-DOPPLERIZED SIGNALS

FOR SAMPLING RATES OF 200, 400, & 800 Hz



CONFIDENTIAL

Figure 13. Artificially-Dopplerized Signals for Sampling Rates of 200, 400 & 800 Hz for Tooth 18

K&E 10 X 10 TO THE INCH 46 0702
7 X 10 INCHES MADE IN U.S.A.
KRUPP & ESSER CO.

ARTIFICIALLY - DOPPLERIZED SIGNALS

for SAMPLING RATES OF 200, 400, & 800 Hz.

22 21 20 19 18 ← TEETH

DOPPLERIZATION AMPLITUDE (VOLTS-PER-HZ)

200 Hz
400 "
800 "

13 SEPT. 1966

L. STRAUSS

P.N. GENERATOR OSCILLATOR FREQUENCY (Hz.)

3500.00 4000.00 4500.00 4000.00 4000.00

Figure 14. Artificially-Dopplerized Signals for Sampling Rates of 200, 400 & 800 Hz for Teeth 19, 20, 21 & 22

~~CONFIDENTIAL~~

UNCLASSIFIED

UNCLASSIFIED CONFIDENTIAL